

Payload Isolation and Stabilization  
By A Suspended Experiment Mount (SEM)

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ABSTRACT

Many Space Shuttle and Space Station payloads can benefit from isolation from crew or attitude control system disturbances. Preliminary studies have been performed for a Suspended Experiment Mount (SEM) system that will provide isolation from accelerations and stabilize the viewing direction of a payload. The concept consists of a flexible suspension system and payload-mounted control moment gyros. The suspension system, which is rigidly locked for ascent and descent, isolates the payload from high frequency disturbances. The control moment gyros stabilize the payload orientation. The SEM will be useful for payloads that require a lower-g environment than a manned vehicle can provide, such as materials processing, and for payloads that require stabilization of pointing direction, but not large angle slewing, such as nadir-viewing earth observation or solar-viewing payloads.

(NASA-TM-107941) PAYLOAD ISOLATION AND  
STABILIZATION BY A SUSPENDED EXPERIMENT  
MOUNT (SEM) (NASA) 23 p

N92-28369

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G3/18 0106537

## INTRODUCTION

The orbiter motion environment is an important consideration for both low-g and viewing types of payloads. Low-g payloads are sensitive to linear and angular accelerations, while viewing payloads are sensitive to the first and second integrals of angular acceleration. There are several sources of disturbance that prevent the orbiter from achieving an ideal, disturbance-free environment for these payloads. Man motion and attitude control system operation are the most significant accelerations. Gravity gradient and aerodynamic accelerations are much smaller. The integrals of these accelerations, which are the pointing stability and jitter, are limited by the attitude control system deadband and drift rate.

This paper describes a concept for a payload isolation and stabilization system [the Suspended Experiment Mount (SEM)], which has been studied for several years by Marshall Space Flight Center. The payload requirements and orbiter performance that led to consideration of this concept will be described, followed by a description of the concept, and finally a discussion of the performance expected from the concept.

## PAYLOAD REQUIREMENTS

We consider two types of motion disturbances: accelerations, both linear and angular; and line of sight disturbances, which are strictly angular motion. Payloads that are sensitive to accelerations are collectively referred to as low-g payloads. Depending on the individual payload considered, the desired linear acceleration environment ranges from  $10^{-3}$  to  $10^{-6}$  g (1000-1  $\mu$ g). Angular accelerations are significant to many low-g payloads only because they induce linear accelerations due to the displacement of the payload from the orbiter center of mass. In this case, locating the payload as close as possible to the center of mass can alleviate the problem. However, some payloads, in particular those involving fluids, are sensitive to angular accelerations.

Table 1 lists accelerations due to various disturbance sources on the orbiter. Man motion and vernier thruster firing are the largest sources of disturbance accelerations and are comparable in magnitude. Typical acceleration environments for the orbiter under control of the vernier RCS thrusters are in the range of  $10^{-3}$  to  $10^{-4}$  g. If the orbiter is placed in a gravity gradient stabilized attitude, thruster disturbances can be eliminated for a period of time and the acceleration levels are reduced about an order of magnitude, which is still well above the 1  $\mu$ g level desired by some payloads. Thermal and communications constraints may also limit the duration for which a particular attitude, such as the gravity gradient attitude, can be maintained. This imposes additional operational constraints on the payload.

Linear acceleration induced by rotational motion of the orbiter can be significant if the payload is not located at the orbiter center of mass. Displacements of as little as one meter from the center of mass result in accelerations due to rotation that are comparable to the direct linear component.

Low-g operations currently require that other orbiter activities be curtailed. This limits operations to either dedicated Shuttle flights, flights which deploy free-flying satellites, or dedicated portions of other shared flights. One objective of the SEM is to reduce these restrictions by isolating the payload from orbiter disturbances.

TABLE 1. ACCELERATIONS DUE TO VARIOUS DISTURBANCE SOURCES

- Reaction Control System (RCS) Thrusters

Vernier system       $2 \times 10^{-4}$  g linear  
                           $3 \times 10^{-4}$  rad/sec<sup>2</sup> rotational

Primary system      0.04 g linear  
                           $2 \times 10^{-2}$  rad/sec<sup>2</sup> rotational

- Man Motion               $1 \times 10^{-4}$  g linear acceleration  
                           $2 \times 10^{-4}$  rad/sec<sup>2</sup> rotational

- Gravity Gradient Torque       $2 \times 10^{-6}$  rad/sec<sup>2</sup> rotational

- Aerodynamic Drag       $10^{-6} - 10^{-7}$  g linear (varies with attitude and altitude)

- Centrifugal Force       $1 \times 10^{-3}$  rad/sec rotational (for earth reference rotation) ( $1 \times 10^{-3}$  units/sec<sup>2</sup> linear acceleration)

Pointing requirements for viewing-type payloads vary widely depending on the payload objectives. Some, such as cosmic ray detectors, require only coarse orientation and stabilization, which can easily be provided by the orbiter. Others have more stringent pointing and stabilization requirements. Among the latter, we can distinguish those that view a single target, such as the sun or earth, and those that view multiple targets sequentially, such as astronomical telescopes. There are basically three choices at present to satisfy payload pointing requirements: 1) hardmount the payload to the orbiter and use the orbiter for both orientation and stabilization, 2) use the Spacelab Instrument Pointing System to orient and stabilize the payload, and 3) provide a pointing system as an integral part of the payload.

Option 1 has the advantage of simplicity. No payload mechanisms are required, and resources can be provided to the payload across a rigid interface. However, pointing accuracy and stabilization are limited by the orbiter attitude control system, by structural distortion and misalignment between the orbiter inertial measurement unit and payload, and by thruster fuel use. The ability to change targets sequentially is limited by thruster fuel use and rotation rates to about 2 or 3 targets per orbit maximum, and contamination increases with increased thruster use. The absolute pointing accuracy can be improved by providing payload attitude sensors that eliminate the bias errors between the orbiter and payload at the cost of increased payload and integration complexity.

Option 2 provides high accuracy pointing and stabilization and the ability to change targets through large angles rapidly and often. However, the resources provided across the gimbal to the payload are limited (in particular there is no provision for thermal control fluid), payload integration is much more complicated than for hard-mounted payloads, and IPS availability is limited. The IPS is capable of supporting large payloads, so small instruments must be grouped into a single payload for efficient use, which also increases the integration complexity. The orbiter attitude control system would still be required for this option and contamination due to thruster fuel might be of concern for some instruments.

Option 3 is currently used by many small instruments. The pointing system can be optimized for the instrument, but the complexity and cost of both the instrument and its integration are increased, while similar capabilities are redeveloped for many instruments.

Table 2 summarizes the characteristics of the currently available options for payload pointing. An obvious feature of these systems is that there is no direct provision for payloads that require the high accuracy of the IPS but do not require its wide range, rapid slewing ability. The SEM is intended to fill this gap.

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TABLE 2. CHARACTERISTICS OF POINTING ACCOMMODATIONS

Orbiter

- Accuracy - 2 degrees
- Stability - arc minutes (determined by deadband setting)
- Hard-mounted payload
  - Full orbiter resources available
  - Relatively simple integration
- Accuracy can be improved by use of payload attitude sensor
- Target change requires orbiter maneuver

IPS

- Accuracy - 2 arc seconds
- Stability - 1-5 arc seconds
- Pointing cone - 60 degree half angle
- Limited electrical power across gimbal
- Limited signals across gimbal
- No thermal control fluids across gimbal
- Extensive integration effort

Payload Provided

- Optimized for payload
- Increases payload complexity and cost

## SUSPENDED EXPERIMENT MOUNT CONCEPT

The purpose of the SEM is to isolate the payload from disturbance accelerations and to stabilize its orientation. Several concepts have been developed to accomplish this, all of which use a flexible suspension system to passively isolate the payload from high frequency accelerations and control moment gyros (CMGs) for active control of low frequency disturbances and stabilization of the line of sight. In addition, it will reduce the complexity and expense of integration for stabilized payloads by eliminating the need to provide resources across a wide range gimbal system and will be a simpler and less expensive system than a precision gimbal system such as the IPS. Using the CMGs for control of the orbiter, as well as the payload, provides additional advantages by eliminating the contamination associated with the orbiter thrusters and the limitations imposed by thruster fuel budgets. Figure 1 compares the characteristics of various types of pointing systems.

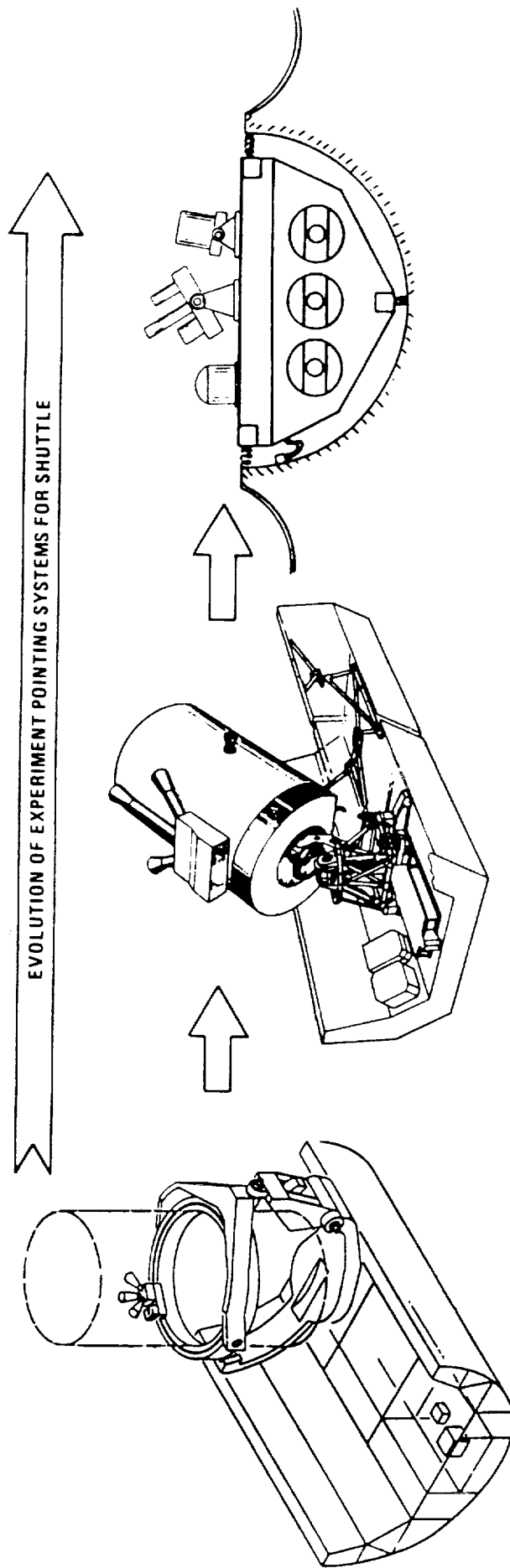
### Suspension System

The suspension system must perform two functions for the SEM: isolate the payload from high frequency disturbances while allowing low frequency control of the orbiter during experiment operation and restrain the payload during periods of high dynamic loads (launch, reentry, and maneuvers). The suspension system, therefore, must be composed of a flexible coupling that can be rigidly locked during periods of high loads.

Figure 2 illustrates a suspension/retention system that uses standard orbiter active sill and keel trunnion fittings for rigid attachment. The flexible suspension incorporates a linear actuator to lift the payload out of the trunnion fittings during operation. This approach has the advantage of using standard orbiter fittings during the critical flight periods.



FIGURE 1. SUSPENDED EXPERIMENT MOUNT

WHY DO WE WANT IT?CONVENTIONAL GIRTH RING  
POINTING SYSTEM

- FIXED GIRTH RING DIAMETER
- FIXED C.G. LOCATION
- ELECTRICAL (AND FLUID) LINES ACROSS LOW TORQUE GIMBALS
- MULTIPLE INSTRUMENTS/SINGLE VIEWING DIRECTION
- INTEGRATION WITHIN NARROW POSITION, VOLUME, C.G. CONSTRAINTS

NASA/ESA INSTRUMENT  
POINTING SYSTEM

- BASE PLATE MOUNT
- LARGER C.G. ENVELOPE
- ELECTRICAL (AND FLUID) LINES ACROSS MEDIUM TORQUE GIMBALS
- MULTIPLE INSTRUMENTS/SINGLE VIEWING DIRECTION
- INTEGRATION RELAXED
- ONLY TWO IN INVENTORY AT HIGH COST

SUSPENDED EXPERIMENT MOUNT

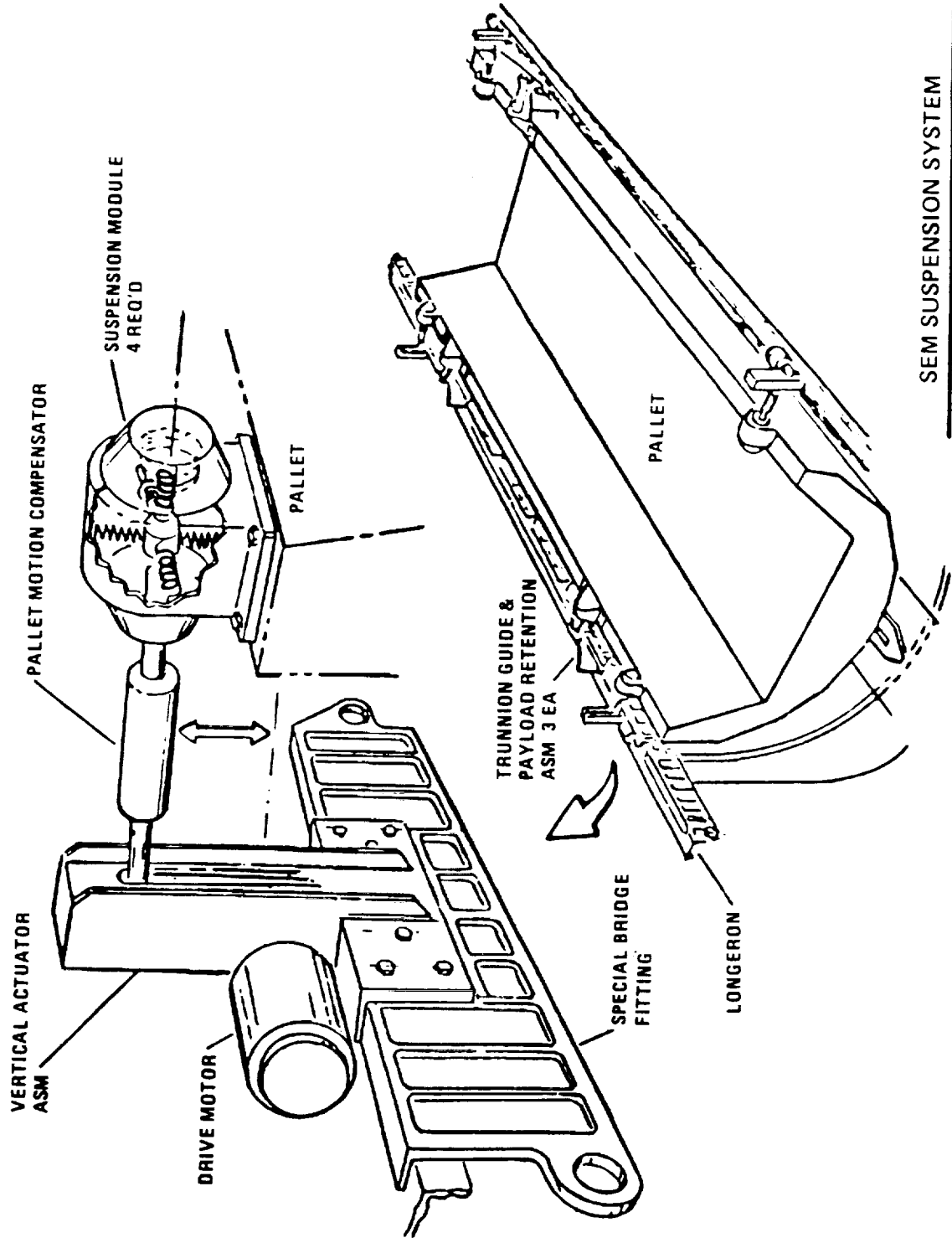
- INDEPENDENT EXPERIMENT MOUNTING
- NO C.G. ENVELOPE CONSTRAINTS
- ELECTRICAL AND FLUID LINE FEED TO PALLET EASILY SATISFIED
- MULTIPLE INSTRUMENTS/MULTIPLE VIEWING DIRECTIONS
- INTEGRATION UNCONSTRAINED BY POSITION, VOLUME, CONTAMINATION FROM THRUSTER FIRINGS, ASTRONAUT MOTION, ETC.
- CAN BE DEVELOPED USING EXISTING EQUIPMENT/TECHNOLOGY AT RELATIVELY LOW COST

– LIMITED FLIGHT OPPORTUNITIES

– LARGE EXPERIMENT MOUNTING AREA  
GIVES INCREASED FLIGHT OPPORTUNITIES

FIGURE 2. IMPLEMENTATION OF THE SUSPENDED EXPERIMENT MOUNT

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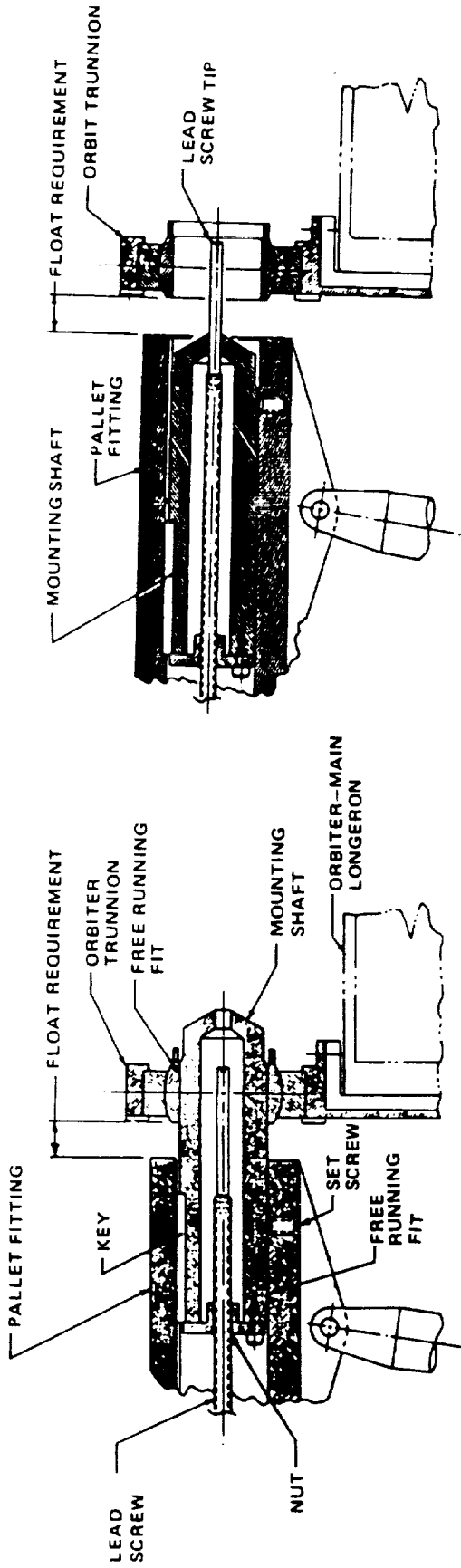
Other possibilities for active retention devices are shown in Figure 3. These concepts have the advantage that the retention system can be released without requiring a linear displacement of the payload, and the retention fittings remain captive even when released. The latter feature helps to alleviate concerns over the reliability of recapture, which has become a significant concern for the ASTRO payload on the IPS.

Helical springs are shown for the flexible suspension system in Figure 2, but there are other options, some of which are listed in Table 3. Thermal control associated with elastomeric isolators adds additional complexity to the SEM, which is undesirable. Linearity simplifies the system behavior, so solid-wire, helical springs and gas-filled bellows are the prime candidates for suspension system isolators. However, lower spring rates (and therefore lower natural frequencies) can be achieved with wire rope helical springs, which allows better passive isolation.

The SEM is intended to provide stabilization and isolation, not offset orientation, so the free motion of the suspension system only needs to accommodate the disturbance motions. These are less than 2 cm for vernier thruster firings or man motion on the orbiter, which can be easily accommodated in the concepts shown. Because of the small relative motion, it is relatively simple to provide electrical power and thermal control fluids from the orbiter to the payload. Complex cable wrap or slip ring mechanisms are not required. Power cable and fluid plumbing stiffness sets a lower limit to the useful isolator spring rates, however. Attention must therefore be paid to techniques for reducing this stiffness.

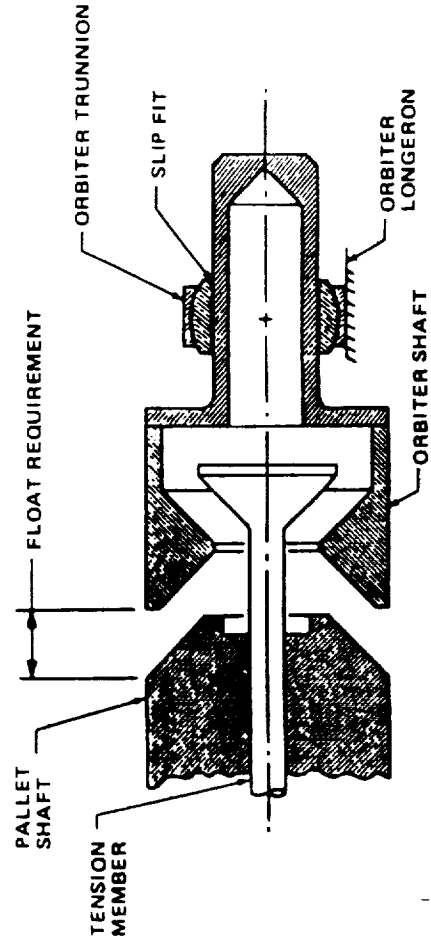
Isolation from disturbances for low-g payloads can be provided with the suspension system alone, without the active CMG control discussed below. Figure 4 shows typical results for the degree of isolation that can be achieved at various suspension system natural frequencies. About an order of magnitude attenuation of disturbances can be expected for straight forward suspension system designs.

FIGURE 3. OTHER SUSPENSION/ISOLATION OPTIONS

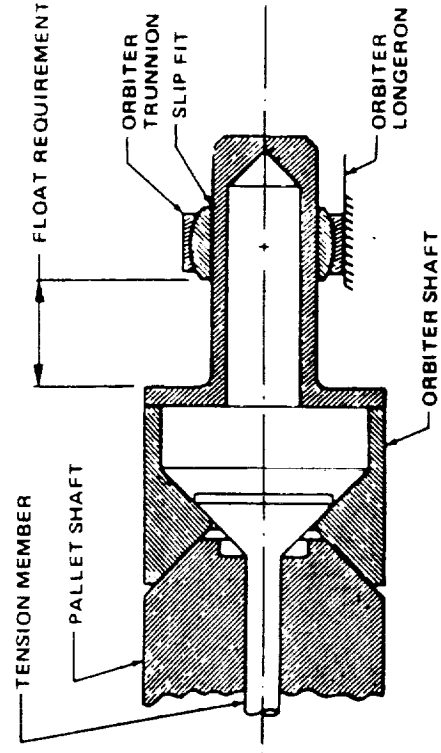


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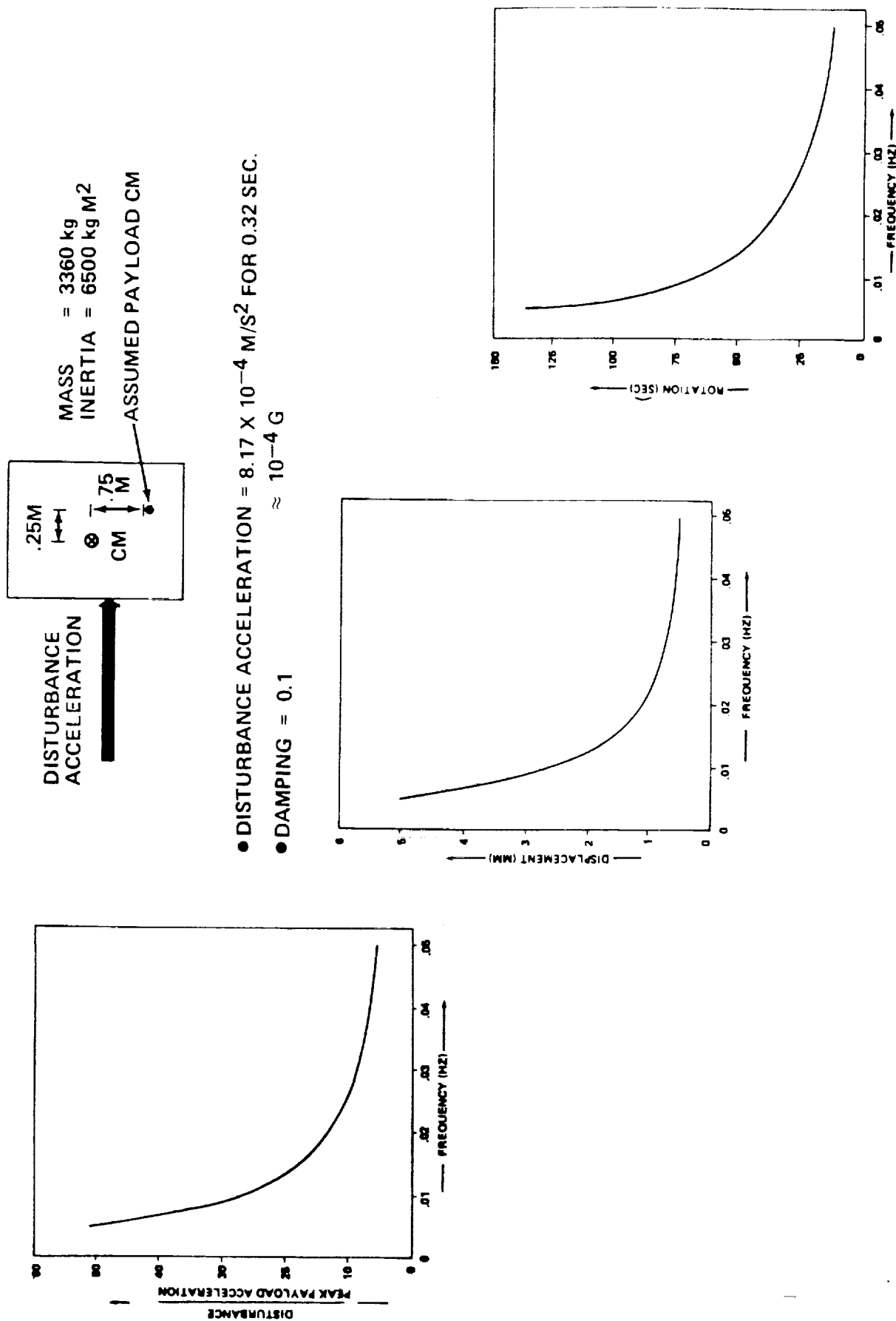
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TABLE 3. SUSPENSION/ISOLATION CONCEPTS

<u>ISOLATOR OPTIONS</u>	<u>CHARACTERISTICS</u>
● ELASTOMERIC	<ul style="list-style-type: none"> <li>- NON-LINEAR LOAD VS. DEFLECTION</li> <li>- HYSTERETIC DAMPING (5% TO 15%)</li> <li>- TEMPERATURE SENSITIVE REQUIRING THERMAL CONTROL</li> </ul>
● WIRE ROPE HELICAL SPRING	<ul style="list-style-type: none"> <li>- NON-LINEAR LOAD VS. DEFLECTION</li> <li>- FRICTION DAMPING 15% TO 20%</li> </ul>
● SOLID WIRE HELICAL SPRING	<ul style="list-style-type: none"> <li>- LINEAR LOAD VS. DEFLECTION</li> <li>- HYSTERETIC DAMPING 0.5%</li> <li>- REQUIRES ADDITIONAL DAMPING</li> </ul>
● GAS FILLED BELLOWES	<ul style="list-style-type: none"> <li>- LINEAR LOAD VS. DEFLECTION</li> <li>- VISCOUS DAMPING 10% (BASED ON GAS FLOW)</li> <li>- INSENSITIVE TO TEMPERATURE RANGE</li> <li>- SIMPLE SPRING/DAMPER INTEGRAL DESIGN</li> </ul>

FIGURE 4. PASSIVE ISOLATION SYSTEM

PRELIMINARY RESULTS



### CMG System

The SEM can be built using the spare Skylab CMGs. Some modifications to the CMGs have been considered to upgrade their performance but are not required to implement the SEM. Likewise, the isolator suspension system is not necessary to use the CMG active control, but better stabilization can be achieved with the combination of CMGs and suspension system. Table 4 summarizes the pointing/control considerations.

The CMG system is used to control both the payload and, through the suspension system, the orbiter. Avoiding orbiter thruster firings reduces disturbances to the payload and reduces contamination, which is a significant benefit to many payloads. Equally important from an implementation viewpoint is the simplification that results for the SEM. With the orbiter in a fine pointing control mode, any bias of the orbiter attitude, such as results from structural distortion, IMU drift, or misalignment produces a secular torque due to thruster firings on the payload, which can quickly saturate the CMGs. It is possible to use SEM attitude sensors to control the orbiter attitude control system, but this requires an additional interface with the orbiter. Since the SEM is capable of controlling the orbiter, and contamination is also reduced, we prefer to avoid use of the orbiter thrusters.

Saturation is a concern for any momentum-based attitude control system. The SEM is capable of operating for several orbits before desaturation is required. Desaturation requires that an external torque be applied to absorb the accumulated angular momentum. Orbiter thrusters are one possible source of this torque. Another possibility is to use gravity gradient torques either by flying an attitude that produces negligible secular torques or by periodically maneuvering to an attitude where gravity gradient and aerodynamic torques cause an accumulation of angular momentum in a desired direction. Offset pointing mechanisms are required for the payload in this case of gravity gradient dumping of momentum, since the orbiter attitude is not related to the viewing direction. These mounts are relatively simple since they are operated open loop in a position and hold mode and provide the added benefit that several instruments can view different directions simultaneously.

TABLE 4. POINTING/CONTROL CONSIDERATIONS

<u>DYNAMIC CHARACTERISTICS:</u>	<u>HARDMOUNTED</u>	<u>ISOLATOR MOUNTED</u>
SEM STABILITY	± 2 ARC MIN	± 1 ARC SEC
SEM STABILITY RATE (JITTER)	± 1 ARC MIN/S	± 1 ARC SEC/S
ORBITER RELATIVE MOTION	NONE	± 3 ARC MIN
ORBITER RELATIVE TRANSLATION	NONE	± 2 CM
<u>CMG MOMENTUM:</u>	<u>GRAVITY GRADIENT ONLY</u>	<u>+20% AERO</u>
ORBITER X-AXIS PERPENDICULAR TO ORBIT PLANE	2350 NMS/ORBIT	2820 NMS/ORBIT
ORBITER X-AXIS IN ORBIT PLANE	7650 NMS/ORBIT	9180 NMS/ORBIT
<u>OPERATIONAL TIME UNTIL CMG DESATURATION:</u>		
USING ORBITER VCS THRUSTERS	2 TO 6 ORBITS	
USING GRAVITY GRADIENT DUMP WITH OFFSET POINTING MECHANISMS	INDEFINITE	



## SUMMARY

The Suspended Experiment Mount (SEM) is a concept that provides isolation and/or stabilization for payloads carried on a disturbance prone facility such as the Space Shuttle Orbiter or a manned Space Station. Artists' concepts of the SEM with payloads in the orbiter are shown in Figures 5, 6, and 7. It has applications for both low-g and viewing payloads, which are summarized in Table 5.

Our studies have shown that the SEM concept is feasible. Table 6 summarizes the characteristics and capabilities that are achievable. Interaction between the SEM and payload is minimal, so existing payloads can use it to enhance their capabilities with little or no modification. The concept is applicable to both Space Shuttle and Space Station payloads. An early flight demonstration can use only the flexible suspension system to provide disturbance isolation, with the CMG system subsequently added to stabilize pointing. Alternatively, the first flight could use the CMG system with the payload hard mounted to the orbiter to provide modest stabilization. The flexible suspension would be added for subsequent flights to improve pointing and provide disturbance isolation. A third option is to go directly to the full SEM on the first flight. The choice depends on the characteristics of the first payload.

FIGURE 5

# SUSPENDED EXPERIMENT MOUNT (SHORT SEM)



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FIGURE 6

# SUSPENDED EXPERIMENT MOUNT (LONG SEM)



FIGURE 7. SPACE STATION ISOLATION CONCEPT  
FOR LOW-G PAYLOADS

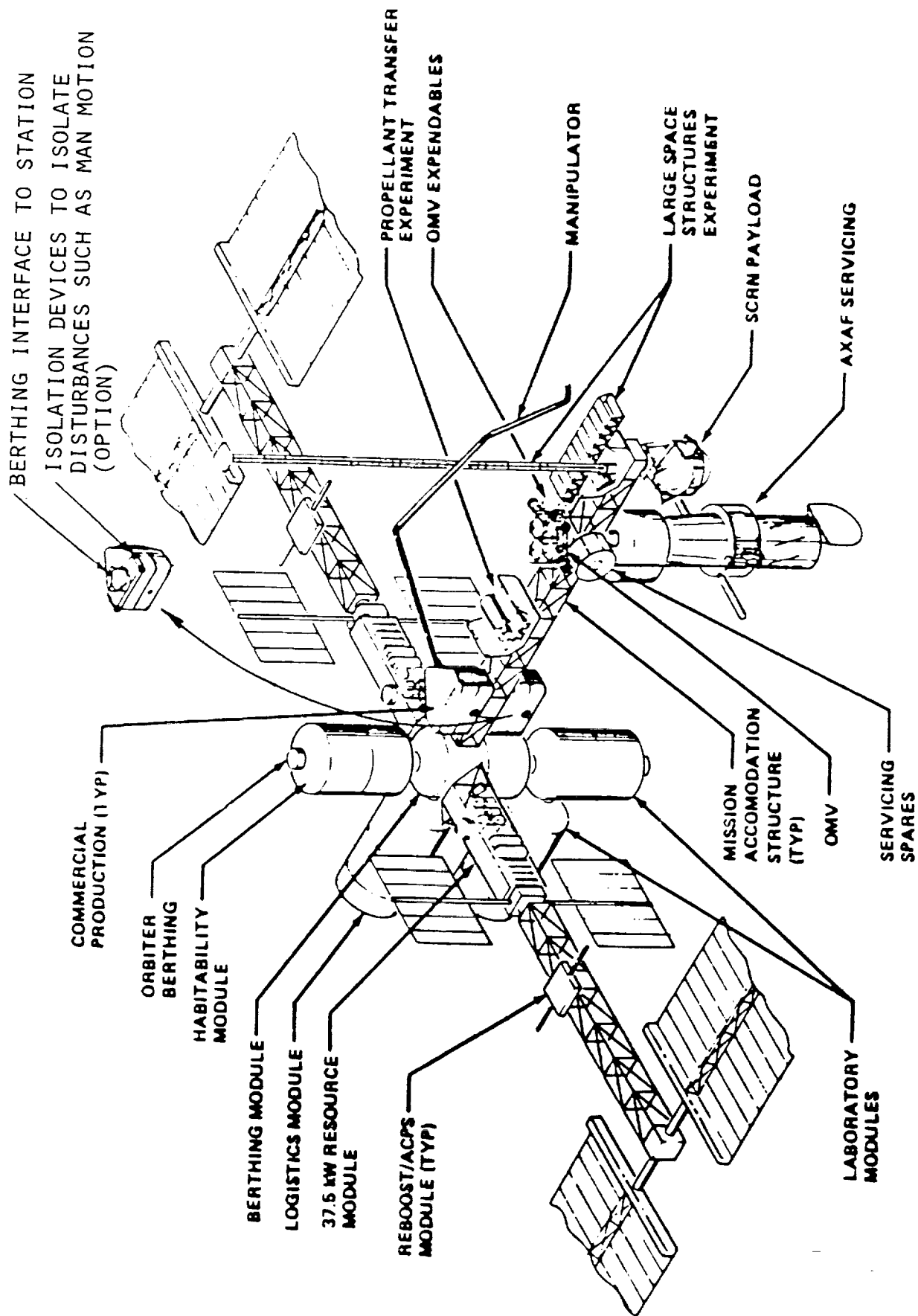


TABLE 5. APPLICATIONS

PASSIVE ISOLATION SYSTEM

- ISOLATE PAYLOADS FROM SPACE STATION/ORBITER DISTURBANCES
- GIVES HIGH FREQUENCY ATTENUATION
  - MAN MOTION
  - THRUSTERS
  - DOCKING/BERTHING
- SUITABLE FOR LOW-G PAYLOADS
- MAY ACCOMMODATE SOME VIEWING PAYLOADS
  - GOOD SHORT-TERM STABILITY/NO IMPROVEMENT TO LONG-TERM STABILITY
  - APPLICABLE TO PAYLOADS WITH MODERATE ACCURACY REQUIREMENTS AND SHORT FRAME TIMES

ISOLATION SYSTEM WITH CMGs

- PROVIDES STABLE VIEWING PLATFORM
- SUITABLE FOR PAYLOADS WITH ONE VIEWING DIRECTION
- MULTIPLE VIEWING DIRECTIONS REQUIRE SIMPLE POSITION AND HOLD MOUNT
- WOULD INTERACT WITH PRIMARY SPACE STATION CONTROL SYSTEM
  - DISTRIBUTED CONTROL SHOULD BE INVESTIGATED

TABLE 6. SUMMARY

SUSPENDED EXPERIMENT MOUNT (SEM)

- THE SEM PROVIDES PALLET-MOUNTED EXPERIMENT POINTING AND SHUTTLE CONTROL WITHOUT RCS
  - REDUCED CONTAMINATION DURING EXPERIMENT OPERATIONS
  - INCREASED EXPERIMENT VIEWING CAPABILITY
- PROVIDES A SOLID STRUCTURE FOR LAUNCH/REENTRY LOADS AND A STABILIZED EXPERIMENT BASE FOR ON-ORBIT OPERATIONS
  - 2 ARC MIN STABILITY FOR HARD-MOUNTED PALLET
  - 1 ARC SEC STABILITY WITH SUSPENSION SYSTEM
  - ORDER OF MAGNITUDE OR BETTER REDUCTION OF G-DISTURBANCES
- INTEGRATION AND SHUTTLE INTERFACES MORE EASILY SATISFIED FOR EXPERIMENTS WITH STRINGENT POINTING REQUIREMENTS
  - INDEPENDENT EXPERIMENT MOUNTING
  - ELECTRICAL AND FLUID LINE FEED TO PALLET EASILY SATISFIED
  - LITTLE TO NO EXPERIMENT CG ENVELOPE CONSTRAINTS
  - RELATIVELY SIMPLE OFFSET POINTING MECHANISMS GIVE MULTIPLE VIEWING DIRECTIONS WITH SHARED FINE POINTING STABILITY
  - LARGE EXPERIMENT MOUNTING AREA GIVES INCREASED FLIGHT OPPORTUNITIES